Impact of Low-Head Hydropower Generation at Morgans Falls, LaHave River on Migrating Atlantic Salmon (*Salmo salar*)

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Abstract

A low-head hydro-powered electric generation facility at Morgans Falls, LaHave River, Lunenburg County, Nova Scotia, opened in 1996. The facility is adjacent to an existing fishway and counting trap used to monitor salmon migration since 1972. The impact attributed to mortality of Atlantic salmon (*Salmo salar*) smolts migrating downstream on the salmon population above the falls is assessed. Operating conditions of the facility were established prior to licensing, and effects monitoring concentrated on estimating facility use, louver efficiency and turbine mortality rates through controlled release of hatchery grown and differentially marked smolts. Estimates of facility use were 47.1% and 52.1%; louver efficiencies were 86.3% and 88.3% or 96% if smolts recovered from the bypass tank were included. Turbine mortality estimates ranged from 15.4% to 78.5%. The wide range in turbine mortality estimates was attributed to uncertainties about escapes from the experiment and the causes of mortality. Impact analysis was performed by simulation using uncertainties for all input variables. At the estimated 1997 wild smolt population of 17,289 ± 256 and at an average louver efficiency of 87.3% the most probable smolt mortality was about 459 smolts or about 22 potential salmon returns over two years. At the 90th percentile of potential loss, impact was about 683 wild smolts or the equivalent of about 2.1% of the historic count of adult salmon ascending the Morgans Falls fishway. The estimated level of loss in returns is indistinguishable in the existing assessment model. Comparisons with existing data, design criteria, formulae, problems associated with the design and recommendations for repeating portions of the experiment are made. The significance of the impact could not be assessed without an established allowable effect.

Résumé

Une installation hydroélectrique de basse chute a été ouverte aux chutes Morgan, sur la rivière LaHave, comté de Lunenburg, Nouvelle-Écosse, en 1996. La station est située près d'une passe migratoire et d'un piège de dénombrement utilisé pour contrôler les migrations du saumon depuis 1972. On évalue ici l'impact attribuable à la mortalité des saumoneaux de l'Atlantique (*Salmo salar*) migrant en aval sur la population de saumon en amont des chutes. Les conditions d'exploitation de l'installation ont été établies avant l'attribution du permis et la surveillance des effets, qui a porté essentiellement sur l'estimation de l'utilisation de l'installation, sur l'efficacité des volets, et sur les taux de mortalité aux turbines, a été réalisée à l'aide d'un largage contrôlé de saumons d'écloserie porteurs de marques différentes. Les estimations chiffraient l'utilisation de l'installation à 47,1% et 52,1%; l'efficacité des volets était de 86,3 % et 88,3 %, ou de 96 % si on incluait les saumoneaux recueillis dans le bassin de dérivation. Les estimations de la mortalité aux turbines allaient de 15,4 % à 78,5 %, le vaste écart entre ces valeurs étant attribué à des incertitudes concernant les poissons évadés de l'effectif expérimental et les causes de mortalité. L'analyse des impacts a été fondée sur une simulation tenant compte des incertitudes pour toutes les variables d'entrée. En se fondant sur la population de saumoneaux sauvages de 1997, chiffrée à 17 289 ± 256 et sur une efficacité moyenne des volets de 87,3 %, la mortalité la plus probable était d'environ 459 saumoneaux, soit approximativement 22 remontes éventuelles de saumons en deux ans. Au 90^{e} centile de perte possible, l'impact était d'environ 683 saumoneaux sauvages, soit l'équivalent d'environ 2,1 % du nombre historique de saumons adultes remontant la passe migratoire des chutes Morgans. On ne peut distinguer la perte estimée en remontes dans le modèle d'évaluation actuel. On procède ici à des comparaisons avec les données dont on dispose, les critères de calcul, les formules et les problèmes associés au calcul, et on formule des recommandations sur la reprise de parties de l'expérience. L'importance de l'impact n'a pu être évaluée en l'absence d'effet admissible établi.

Introduction

Interest in low-head (less than 15 m) mini (less than 2.0 kw) hydro-electrical power generation, operating without water storage, has increased with the design of small efficient hydro-powered generators and the availability of development agreements among government, manufacturers and utilities. Part of the impetus for these agreements is to foster the development of hydro power which is perceived to have less impact on migratory fish production than traditional high-head hydro power. The opening in 1996 of a low-head hydro facility, operated by Morgan Falls Power Company (MFP) and located on the LaHave River at Morgans Falls, New Germany, Nova Scotia (Figure 1) provided an opportunity to assess the impact of a low-head hydro facility on the downstream migration of Atlantic salmon (*Salmo salar*) smolts. The site (Figure 2) is opposite to an upstream fishway established and monitored since 1970. Together these facilities provide two-way monitoring of the movement of fish at Morgans Falls. These facilities can provide data necessary for the assessment of loss in Atlantic salmon production resulting from losses attributed to downstream fish passage at a low-head hydro facility.

The design and construction of the hydro facility was preceded by a Water License Application through the Department of Environment, Province of Nova Scotia. Part of this process was a referral to the Department of Fisheries and Oceans (DFO), Canada, for compliance with the Fisheries Act, pertaining to the requirement to provide adequate fish passage. Design and operating conditions of the facility were described in technical drawings submitted by the proponent and, following review and assessment for compliance to the act, licensing and operating conditions were recommended. Continued operation of new facilities may be contingent upon evidence that no "significant" negative impact on the fisheries resources has resulted from the project. To this purpose these projects require an Effects Monitoring Program (EMP) following installation and operation. Final operating permits may be contingent on the results of the EMP.

Responsibility for providing effects monitoring, acceptable to DFO Habitat Management Division (the lead Division for Water Use referrals), remains with the proponent. Because of the location of the Morgan Falls Power project and the opportunity it provided for two-way monitoring of fish migration, DFO Habitat Management and Diadromous Fish divisions provided advice in the design and assisted in the implementation of the plan in 1997. Under the agreement an advisory committee was formed consisting of the proponent, The LaHave River Salmon Association (LRSA), the Nova Scotia Salmon Association, the Atlantic Salmon Federation, the Nova Scotia Department of Fisheries, the Nova Scotia Department of the Environment and DFO. Preliminary results of this assessment were provided to the committee on November 13, 1997. This document formally presents the data and analysis.

May is the principal smolt migration time in the LaHave River (Hayes 1953). Effects monitoring at the Morgan Falls Power facility for Atlantic salmon smolts concentrated on estimating three rates: 1) the facility use rate for downstream migrating smolts; 2) the louver efficiency rate for smolts entering the power canal; and 3) the turbine mortality rate for smolts passing through the turbine. In addition to these rates, estimates of the number of wild smolt produced above Morgan Falls were derived and together with adult salmon data collected at the Morgans Falls Fishway were used to assess the potential impact of the facility on the salmon population.

Site layout and operation

A 735 kW "S" type Kaplan turbine produces electrical power with a four-blade 1.524 m diameter runner. In front of the runner are moveable multi-vane wicket gates that control the volume, flow rate and therefore RPM of the turbine. The synchronous speed of the turbine is 300 RPM and the runaway speed is 840 RPM. Under normal operating conditions there is about 6.0 m of head or drop in elevation (Figure 3).

Intake to the turbine is behind a louver array (Figure 4) which is placed diagonally in the forebay channel and is designed to deflect downstream migrating fish to a fish bypass (Figure 5). The forebay channel is sized to provide a mean water velocity of 4 fps (1.22 m/s) in the approach to the louvers when the turbine is operated at the maximum rated discharge of 424 cfs (12.01 m^3/s) and when the headpond is at the spillway crest elevation of 165.5 feet (50.44 m). During periods of high flow, when the headpond is higher than the spillway crest, the approach velocity to the louvers is lower than 4 fps (1.22 m/s). During the downstream fish migration period, the turbine is not permitted to operate with flows less than the maximum rated discharge.

The 1.5 foot (0.45 m) wide fish bypass (Figure 5) at the end of the louver line has a downward opening slide gate that is self-regulating. It is normally set to maintain 40 inches (1.02 m) of flow depth over the gate for all forebay water elevations. This provides a flow of 30.4 cfs (0.86 m^3/s) at a velocity of 6.1 fps (1.86 m/s). Therefore the acceleration factor to the fish bypass is 1.52 with the headpond at the spillway crest elevation. At higher headpond levels the acceleration factor is greater because the approach velocity to the louvers is lower and the fish bypass water velocity is constant at 6.1 fps (1.86 m/s).

On May 21, 1997, the water velocities in the forebay channel were obtained with a Gurley model 622 hydrology meter using the two-point method. In the two-point method of measuring velocities, observations are made in each vertical at 0.2 and 0.8 of the depth below the surface. The average of these two observations is taken as the mean velocity in the vertical. Current meter readings were taken at two-foot (0.61 m) intervals across the 16 foot (4.88 m) wide forebay channel with the first and last readings being one foot (0.30 m) away from the side walls of the channel. The total flow was found to be 470.8 cfs (13.34 m^3/s) at a mean velocity of 3.8 fps (1.16 m/s) with the water surface at elevation 166.2 feet (50.66 m). Since there was not a significant change in water levels on May 22 and 23, 1997, it is assumed that the flow and velocities were the same as on May 21.

On May 21 and 22, 1997, the bypass gate was set 25 inches (0.64 m) below the surface to provide a flow of 15.0 cfs (0.42 m^3/s) at a velocity of 4.8 fps (1.46 m/s). Therefore the bypass acceleration factor was 1.26.

On May 23, 1997, the bypass gate was set 40 inches (1.02 m) below the surface to provide a flow of 30.4 cfs (1.86 m/s) at a velocity of 6.1 fps (1.86 m). Therefore the bypass acceleration factor was 1.61.

The purpose of the bypass collection tank is to dissipate the energy of the water falling from the bypass gate and when operating in the assessment mode, to separate most of the water from the successfully deflected fish. Water level in the bypass pool is controlled by adjustment of two de-watering gates downstream and below the fish separator screen and discharges to the river below the fish assessment area (Figure 6). The exit to the bypass collection tank is gated

and when opened fish collect in a collection gallery tank in the fish assessment evaluation area. This tank is shallow enough to observe the presence of smolt. When smolts were observed in the collection gallery tank the exit gate was opened and fish were allowed to enter a counting tank. These tanks, which were narrower and deeper than the collection tank, allow the operator to dip, examine and pass the smolts over a separator screen for exit through the exit pool and discharge pipe.

Operating conditions

Stream discharge gauging

A stream discharge gauging station was established at the first highway bridge 572 m upstream of Morgans Falls, above the influence of the power station and the low-head weir. A staff gauge was installed on the downstream side of the west abutment of the highway bridge. Flow metering has been conducted under several stages of river flow to establish a preliminary stage-discharge curve that is filed as DFO drawing number M - 4127, Rev., March 7, 1997. The total flow in the LaHave River at Morgans Falls was obtained by reading the staff gauge and using the curve to estimate the corresponding flow.

The stream discharge station was established to monitor if the turbine was operating in compliance with the flows specified in the Ministerial approval. From April 1 to November 15, the turbine is licensed to operate with a minimum flow of 424 cfs. Optimum approach water velocity for the louver bypass system is provided with a turbine flow of 424 cfs. For the remainder of the year while there is negligible downstream migration of fish, the turbine is licensed to operate at reduced flows.

Headpond water-level staff gauge

A headpond staff gauge was installed on the forebay-training wall close to the trash racks (see DFO file SK - 1, dated April 18, 1998). The gauge was installed relative to the low head weir, which has a crest elevation of 165.5 feet. A gauge reading of 5.5 feet is at the same elevation as the crest of the weir.

Water flow and operating conditions at spill locations at Morgans Falls

The headpond staff gauge reading can be used to calculate the water flow at the various spill locations at Morgans Falls.

Water flow at Morgans Falls occurs at the following locations:

1. The louver bypass has a self-regulating, downward-opening gate located at a 1.5 foot wide opening at the end of the louvers (Figure 4). Maintaining the crest of the gate at 3.33 feet below the headpond water level provides the specified minimum flow of 30 cfs. When the turbine is not operating the louver bypass is shut off.

2. The downstream fish bypass in the low-head weir is a 2.5 feet wide opening provided with stoplogs. A minimum of 1.8 feet of stoplogs is to be removed to elevation 163.7 feet. The specified minimum flow of 20 cfs is provided with 1.8 feet of spill. Normally the stoplogs are not adjusted; therefore when there is spill over the low head weir there is more flow than 20 cfs at the downstream fish bypass. During periods of extreme low flow, the bypass flow is shut down to provide water to the fishway.

3. The low head weir has a total length of 129.5 feet with a crest elevation of 165.5 feet and provides about 6m of head to the turbine.

4. The DFO fishway has a 2.0 foot wide notch with a fixed concrete sill at elevation 161.83 at baffle number 24. Data currently on hand indicates that there is a 0.3 foot drop in water elevation across this baffle from the headpond level.

5. The turbine operates with a minimum of 424 cfs during the April 1 to November 15 fish migration period.

The flow at each of the first three locations listed above can be estimated using the depth of water over the crest or sill and the following formula:

$$Q = CLH^{3/2},$$

where: Q = flow in ft^3/sec
C =3.3 (C varies with the breadth of the weir crest and the depth of water, however, it has been assumed to be constant for all the spill locations for this exercise. Metering at various flows would be required to determine how the coefficient varied with water depth at each location.)
L = length of spill in feet
H = measured head at least 2.5 m upstream of the weir

The flow in the fishway can be approximated by calculating the depth of water over the sill at baffle 24 and using the formula;

$$Q = C*A*(2gh)^{1/2},$$

where: Q = flow in ft^3/sec
C = 0.7 (C varies with the depth of water, however, it has been assumed to be constant for this exercise. Metering at various flows would be required to determine how the coefficient varied with water depth.)
A = area (ft^2) of water at the upstream side of the notch
g = acceleration of gravity, constant at 32.2 ft/sec
h = head difference at the notch

The turbine flow can be estimated by obtaining the total stream discharge from the gauging station and deducting the sum of the calculated flows from the louver bypass, downstream fish bypass in the low head weir, the low-head weir and the fishway.

Example calculations

At an assumed a headpond staff gauge reading of 165.91 feet.

Louver bypass flow = $Q_1 = 3.3 * 1.5 * 3.33^{3/2} =$ 30.1 cfs

Downstream fish bypass flow in low-head weir = $Q_2 = 3.3 * 2.5 * (165.91-163.7)^{3/2} =$ 27.1 cfs

Low-head weir flow = $Q_3 = 3.3 * 129.5 * (165.91-165.5)^{3/2}$ = 112.2 cfs

Fishway flow = $Q_4 = 0.7 * (165.91-161.83) * 2.0 * (2*32.2*0.3)^{1/2}$ = 25.1 cfs

Total of above flows = 194.5 cfs

If we assume the staff gauge reading at the bridge was 98.6 feet at the same time as the headpond gauge was 165.91 feet, then from the stage-discharge curve on drawing M-4127, the total river flow is 650.0 cfs. The turbine flow would be 650.0-194.5 or 455.5 cfs.

Methods

Effects were assessed through: 1) counts of all smolts through the downstream assessment facility in May, of 1997; 2) release of known numbers of tagged hatchery smolts above the facility; 3) estimates of the numbers of marked hatchery smolts released and migrating in 1997; 4) controlled releases of 200 smolts, 100 left ventral and 100 right ventral fin clipped, at three locations across the trash racks (the 25th, 50th and 75th percentile distance intervals) in the entrance to the power canal; 5) controlled release of tagged (small green Carlin) hatchery smolts directly above the turbine intake manifold; 6) removal of dead fish from the turbine tailrace by screen netting and by scuba diver; and 7) retrieval of free-swimming smolts from the tailrace barrier screen using fixed placed fine-mesh hanging nets and by electrofishing the tailrace at the completion of each trial.

A total of 4,750 tagged LaHave River origin smolts cultured at the Mersey Fish Culture Station were released on four dates in 1997 (Table 1). Smolts destined for louver efficiency and mortality testing were pre-sorted at the hatchery, loaded in the morning and arrived at the site and held in temporary streamside tanks on pumped river water at ambient temperature. Two colors of small Carlin tags were applied at the hatchery one-month prior to stocking. The 150 light green Carlin-tagged smolts were used for turbine mortality tests and 600 of the 4,600 small blue Carlin-tagged smolts were differentially fin clipped and used for the louver efficiency tests. The majority of tagged smolts were released at the outlet to New Germany Lake 2.0 km above Morgans Falls.

Fish were counted continuously in the assessment area from May 6 to May 30, 1997 (Table 2). Counts were recorded as the fish exited the bypass collection tank during louver or turbine testing periods and during daytime and evening hours. The bypass collection tank was drained and cleared of fish prior to and following louver efficiency testing. The exit from the bypass collection tank was closed nightly after the migration rate of smolts slowed and the count continued at the next available shift. During power generation in May 1997 no fish were bypassed without being counted.

Smolts were recovered from the tailrace (Table 3) by three means:

1) barrier nets (0.95 cm mesh) on the fish migration barrier screens,
2) a diver equipped with scuba was used to collect fish mortalities from the nets and from the bottom of the tailrace,
3) electrofishing of the tailrace following completion of a turbine mortality trial.

The integrity of the migration barrier nets was checked by the scuba diver before the turbine mortality tests were conducted.

In the louver efficiency tests, smolts were acclimated (for one hour prior to release) in a perforated, velocity reducing, holding box fitted with a release gate on the downstream side. The holding box was attached to and positioned upstream of the trash racks. Six trials of 100 smolts at three locations along the trash racks were conducted two groups at a time. Smolts were marked in equal lots of left and right ventral fin clips applied at the hatchery two weeks before release. Conditions (Table 4) of the three releases at the trash racks for the louver efficiency tests and locations of fin-clipped smolts at all monitoring points (Table 5) were recorded.

A total of 149 small green Carlin-tagged smolts were released into the intake to the turbine adjacent to the powerhouse wall. Smolts were dumped at 10:00 hrs while the turbine was generating. The turbine operated for approximately 3 hrs and then disengaged (free wheeled) and the wicket gates partially closed to reduce flows through the tailrace. The scuba diver and dippers removed dead smolts from the tailrace screen nets. The tailrace was then electrofished to remove the free-swimming smolts in the tailrace.

A 0.5 m, floating anode constructed of 5.0 cm diameter thin wall aluminum tube was used to electrofish the tailrace following the test. The anode was floated and towed by hauling with non-conductive ropes. The anode was activated and towed from the powerhouse discharge area to the tailrace screens. The wicket gates were adjusted to allow a flow such that fish narcotized by the electrical current at the surface would drift and could be retrieved by dip net at the tailrace screen nets. A Coffelt VVP-2c was used to generate 600 volts which resulted in 0.5 amps between the cathode, a 1.5 x 1.0 m copper screen and the anode. Following the experiment two sweeps were made and results recorded for each sweep (Table 3). A two-sweep removal estimate (Seber 1973) was used to estimate the population of free-swimming green-tagged smolts in the tailrace after the experiment.

A final check was made of the nets and bottom of the tailrace by the scuba diver after completion of electrofishing.

The occurrence of significant experimental effects was tested by chi-square analysis. Two group comparisons were based on equal probability contingency and tested using the method of Snedecor and Cochran (1989). Three-by-one tests were basic chi-square tests using equal probability contingency.

Results and Analysis

Facility use rates

For 1997 tagged smolts:

1) Facility Use Rate (%) = (# of tag recaptures/# released) * 100
=2,085/4000
=52.1%

Using all marked (adipose and Carlin-tagged) smolts:

2) Facility Use Rate(%) = (Total capture of marked hatchery smolts in the bypass/ Estimate of the # of hatchery smolt migrating from above Morgans Falls in 1997)*100
= ((8,915+2,085)/(23,344))*100:(Note: 88.4% of smolt stocked above MF)
= 47.1%

Louver efficiency

Right ventral fin clipped:

1) Efficiency (%) =(# rt. ventral recaptured in bypass/ # rt. ventral released)*100
=((84+68+106)/(99+100+100))*100
= 86.3%

Left ventral fin clipped:

2) Efficiency (%) =(# lt. ventral clip recaptured in bypass / # lt. ventral clipped released)*100
=((58+105+102)/ (100+100+100))*100
=88.3%

Turbine mortality

Assuming that non-recovered fish escaped entry to the turbine or passed through the turbine, survived and escaped capture and that all mortalities were recovered, a minimum estimate of turbine mortality is:

1) Mortality(%) = (# of recovered dead smolts/# tagged released smolts)*100
= (23/149)*100
=15.4%

This estimate attributes only recovered and cut mortalities (23 Carlin-tagged mortalities with visible cut marks) to turbine mortality.

Assuming that all recovered mortalities (23 cut and 25 uncut green Carlin-tagged mortalities) are attributed to turbine mortality regardless of their condition then the turbine mortality is:

2) Mortality(%) = (# of recovered dead smolts/# tagged released smolts)*100
= ((23+25)/149)*100
= 32.2%

Using the electrofishing passes to estimate the free-swimming population of survived green tagged smolts in the tailrace, a free-swimming population of 32 green tagged smolts in the

tailrace was estimated. Using this estimate of the survivors we get a maximum turbine mortality of:

3) Mortality(%) = (# of tagged smolts in test- # of live smolts in tailrace)/# tagged released smolts)*100
= ((149-32)/149)*100
= 78.5%

This estimate assumes all smolts entered the turbine and were fragmented beyond recovery and passed through the net.

The electrofishing estimate of the number of live fish in the tailrace raised the live count from 30 to 32 smolts. Therefore there were a maximum of 71 smolts unaccounted for in the experiment. If these smolts met fates similar to those smolts recovered in the experiment then the electrofishing gear did not recover 48 of these smolts and the diver missed 22. Neither the electrofishing efficiency nor the observations by the diver and crew indicated that these numbers of green Carlin-tagged smolts were in the tailrace after the experiment. These observations and data indicate that about 69 smolts did not enter the turbine. If this was the case then turbine mortality rates could have been:

Using only cut mortalities:

4) Mortality(%) = (# of recovered cut dead smolts/(# tagged released smolts - escapes from the experiment))*100
= (23/(149-69))*100
= 28.7%

Using cut and uncut mortalities:

5) Mortality(%) = (# of recovered dead smolts/(# tagged released smolts - escapes from the experiment))*100
= ((23+25)/(149-69))*100
= 60.0%

Wild smolt migration estimates

Estimates of the wild smolt production above Morgans Falls in 1997 was estimated using the recapture efficiency from known releases of tagged- and marked-hatchery smolts and the count of hatchery and wild smolts at the facility. (A mark-and-recapture estimate)

1) Wild smolt migration = (total # of wild and tagged smolts counted) /(# of tagged smolt recaptured / # of tagged smolt released))- # of tagged smolts released above in 1997
= ((8,616+2,085)/(2,085/4,000))-4,000)
= (10,701 / 0.5213) - 4,000
= 16,527

Because this estimate is based on the same tag recapture rate as the facility use rate of the 1997 tagged-smolt recoveries, it yields the same facility use rate for wild smolts.

A second method to estimate the wild smolt migration is to use the estimate of marked smolts migrating in 1997. This is 22,763 or 88.4% of the smolts stocked above Morgans Falls in 1997. (Approximately 12% are not expected to migrate immediately.) Therefore the estimate is:

2) Wild smolt migration = (total # of wild and marked smolts counted) /(# of marked smolts recaptured) / # of marked smolt released))- # of marked smolts released above in 1997
= ((8,616+8,915+2,085)/(11,000/22,763))-22,763)
= (19,616/0.4832)-22,763
= 40,596-22,763
= 17,833

Treatment effects

The experimental effects of fin clipping, location of release along the louvers and acceleration across the louvers were examined by chi-square analysis of the summation of counts. Contingencies based on equal probability of counts for each treatment were used to estimate the expected results for the three release sites. Two group comparisons, fin clip location (marks) and acceleration, were used to test the equal probability hypothesis for these treatments (Snedecor and Cochran 1989). Smolts counted in the bypass assessment facility and those removed from the bypass tank after all tests were completed (Table 6) were summed and used to estimate the marked fish treatment effect.

Proportions of smolts observed during and after the experiment (Table 7) did not indicate a possible significant marking effect. The difference in frequency was not significant by chi-square ($p= 0.86$) (Table 8).

There was no significant treatment effect for release location ($p=0.21$) or for acceleration ($p=0.91$).

Impact analysis

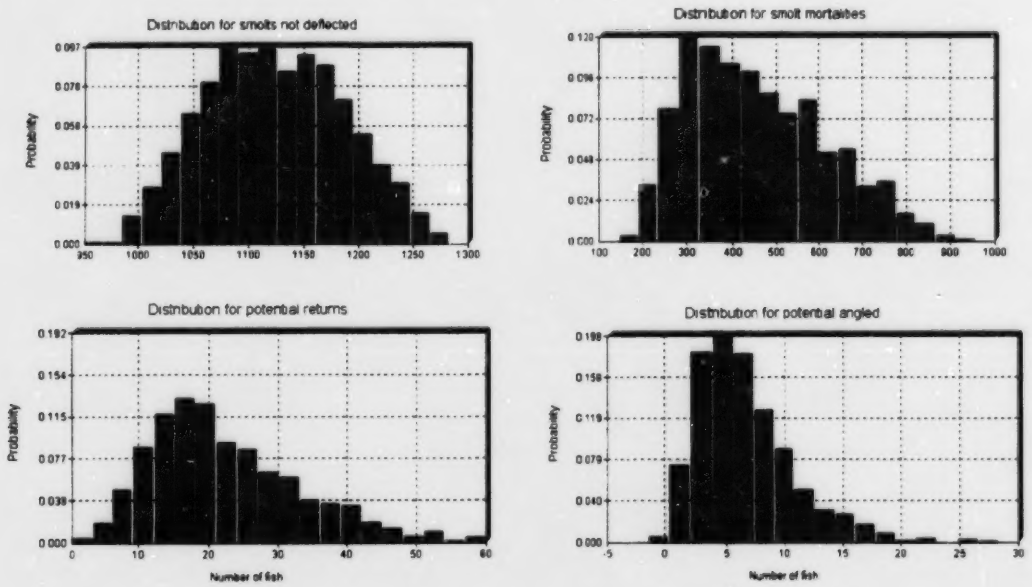
The possible range of the loss of smolts at Morgan Falls Hydro was assessed by applying the observed ranges of facility use, louver efficiency and turbine mortality to the 1997 estimate of the wild smolt migration in a stochastic model using the observed variances, min., max., etc., for each parameter. The deterministic model was:

> 1997 wild smolt loss = wild smolt migration * facility use rate * louver efficiency * turbine mortality

At average values (Table 9) for the parameters used in this model, losses of 426 or 459 wild smolts from the 1997 wild smolt run were estimated (Table 10). These smolt losses would result in the loss of 21 or 22 grilse and salmon in 1998 and 1999. These losses could result in a reduction of 6 or 7 angled fish over two years. These estimates do not include losses of hatchery smolts stocked above Morgans Falls.

Incorporating parameter uncertainty in the above model was performed through simulation analysis. Simulations were run using the clipped-smolt estimator of the wild smolt run and an estimate of variance from the mark re-capture estimate (μ and σ; 17,289 and 256) to derive a

value for a smolt count (one simulation) from the normal distribution of possible smolt counts. The high and low values for the facility use rate (47.1 and 52.1%) were used as limits in a uniform distribution where values for a simulation were selected at random. Louver efficiencies were drawn from a uniform distribution between 86.3% and 88.3%. Turbine mortality was randomly selected from a triangular distribution using the minimum of 15.4%, a most likely mortality of 28.7% and a maximum of 78.5%. The mean from the normal distribution of return rates of hatchery grilse and salmon to Morgans Falls fishway for the period 1974 to 1996 (μ, and σ; 2.43%, and 1.62%) was doubled (μ only, not σ) to estimate the potential number of wild adult salmon returned or angled. Angling exploitation of the returned grilse and salmon was assumed to be the same as most previous observations (Amiro and Jefferson MS1998), 30%, with an assumed standard deviation of 10% drawn from a normal distribution. A total of 1000 simulations contributed to the frequency distributions of possible outcomes. The probability distribution of outcomes for four values: 1) non-deflected smolts; 2) smolt mortalities; 3) potential returns that may have returned; and 4) potential angled fish, follow.



The distributions indicated 90th percentile values of 683 wild smolt mortalities, 37 adult returns and 12 angled fish over two seasons. The ranked sensitivities of adult returns to the rates and distributions used in the model were: 1) louver efficiency; 2) facility use rate and 3) smolt population size.

Losses would double if the wild smolt population doubled and turbine mortality and louver efficiency remained similar to 1997. Estimates of wild smolt populations in 1996 and 1997 are low relative to literature values and process model projections (Korman et al. 1994). Wild smolt runs in the order of twice the 1997 number may be expected.

Stock and recruitment effects

The 90th percentile value annual loss was 683 smolts or about 15 adult salmon to Morgans Falls (22-7 angled or lost to hook-and-release mortality). A loss of 15 adult fish is about 2.1% of the average count of 721 wild grilse and salmon at Morgans Falls fishway, 1974 to 1996. This level of loss (15 grilse and salmon combined) is less than the standard error of the wild salmon count of ±49.0 fish and therefore unlikely to be detected without accounting for variance in the variables which determine annual counts, e.g., smolt production, marine survival, interception, etc. Estimating the effect of these losses in the stock and recruitment of salmon is beyond the resolution of the models and parameters necessary to detect change.

Discussion

The estimated louver efficiencies of 86.3 and 88.3% were higher than previously reported near-surface efficiencies of 80% guidance for Atlantic salmon smolts experiencing a bypass acceleration factor of 1.26:1 (Ducharme 1972). Louver efficiencies of 96% were estimated if fish that were recovered in the bypass holding tank after the experiments were included. Louver efficiencies were not dependent on acceleration factors used in these experiments; however, increased mortalities in the downstream bypass evaluation facility were noted at lower bypass gate settings (higher velocities in the bypass and acceleration across the louvers). Mortalities in the assessment facility were attributed to turbulence in the bypass holding tank and impingement of fish on the incline screen fish separator.

Estimates of turbine mortality ranged from a low of 15.4% to a high of 78.5% depending on the assumption about the missing fish. Assuming that all mortality was attributed to the turbine effect and not to impingement on the temporary nets, and assuming the fates of the undetected smolts were similar to those of the recovered smolts, then mortality was 60.0%. All these figures are much higher than those derived by formula. A point estimate of 5.8% mortality was derived using the formula of Larinier and Dartiguelongue (1989) for a 15.0 cm smolt in a four blade Kaplan turbine with a 1.524 m diameter. Even the minimum experimental mortality observed (15.4%) was outside the range of most values expected by this formula.

It may be argued that the collection nets were the cause of the mortality of uncut smolts recovered on the tailrace screens nets and not exposure to the turbine. However, the presence of many free-swimming smolts in the tailrace indicates that impingement and mortality of uncut smolts was more likely attributed to their trip through the turbine. Under normal operating conditions some of these uncut smolts would not have been impinged on the nets but may have passed through the barrier fence and recovered. However, smolts affected in this way may also experience increased vulnerability to predators and thus have a decreased probability of survival. Predators, birds, fish and mammals were observed both inside and outside the tailrace.

The results of the turbine mortality tests, higher than expected mortality, uncertainty of the experimental effect of the nets and uncertainty of affected but not succumbed smolts may

warrant repeating this portion of the experiment. This is especially true if the results are to be used to assess other proposals.

The simulation analysis was intended to incorporate the uncertainty in all parameters used in assessing the impact of the facility on the Atlantic salmon population above Morgans Falls. This procedure also indicated the sensitivity of the site configuration and therefore where improvements to further reduce losses may be warranted.

The analysis indicates that repeating the entire assessment is largely unwarranted. However, further clarification of the turbine mortality loss would benefit the transportability of these results but we expect would not significantly alter the impact assessment. This is because improvements to the experimental design would seek to eliminate undetected smolts and the experimental effect of the nets. These data could only lower the median turbine mortality value used in the deterministic evaluation. The simulation analysis was less dependent on this value because it was selected from a triangular distribution with a peak (modal value) of 28.7%, which is lower than mean value of the 40.9%. We chose 28.7% as the most likely value in the triangular distribution because it represented a mode of these assumptions. We chose the 90th percentile to reflect a cautious, risk adverse position. At this level of risk acceptance the losses we expected were not likely to be detectable. The analysis indicated a most probable loss of 1.2% of the run. The acceptability of this loss could not be evaluated without *a priori* definition of "significant impact". No definition was given.

Acknowledgements

We thank the Morgan Falls Power Company for access to the site and assistance in conducting the experiments. The LaHave River Salmon Association provided funding for two university students to assist with the experiments, Mr. J.P. Kennedy and Mr. J. Spence. Mr. Eric Jefferson (DFO) and Mr. J.P. Kennedy provided valuable assistance both with the collection and compilation of the data. Mr. J. Close (DFO) and Mr. H. Caracristi (DFO) conducted the flow measurements, engineering surveys and provided the technical drawings. Dr. T.L. Marshall provided critical review of an earlier manuscript and provided comment that greatly improved the manuscript. Ms. K. Rutherford provided editorial comment on the manuscript. We thank each for their valuable contribution.

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Tables/Figures

Table 1. Numbers, locations, dates and markings of Atlantic salmon hatchery-reared smolts released in the LaHave River, 1997.

	Above Morgans Falls					Total above Morgans Falls	Total below Morgans Falls	Grand Total
		Power	New Germany Lake					
Release Date	Turbine	canal	Tagged		Untagged			
8-May			1,333		7,000		16,000	
12-May							4,524	
20-May			1,333		7,000			
21-May		200 n						
22-May		200 n						
23-May		200 n						
26-May	150 t							
28-May			1,333		7,692		7,967	
Totals	150	600	4,000	c	21,692	26,442	28,491	54,933

n tags and marks applied (Right and Left Ventral fin clips).
t Tagged small green Carlin, separate series.
c Combined tag numbers only

Table 2. Atlantic salmon smolts and parr counted in the bypass assessment facility at Morgan Falls Hydro, 1997.

Date	Wild smolt	Hatchery smolt	Tagged hatchery smolt	Wild parr	Test Number and ventral fin mark					
					#1 Right	#2 Left	#3 Left	#4 Right	#5 Right	#6 Left
6-May	10	1	0	1						
7-May	14	4	0	1						
8-May	49	1	0	8						
9-May	15	3	0	2						
10-May	37	0	0	0						
11-May	6	0	0	1						
12-May	195	13	2	2						
13-May	308	13	3	8						
14-May	917	86	6	26						
15-May	1049	90	19	12						
16-May	863	100	20	10						
17-May	925	97	19	14						
18-May	86	18	5	4						
19-May	498	50	18	8						
20-May	491	524	109	9						
21-May	299	969	227	7	25	29				
22-May	229	1492	339	13	59	29	55	28	77	79
23-May	442	508	61	15			50	40	24	22
24-May	148	124	20	9					3	1
25-May	319	96	10	30					2	
26-May	791	145	26	11						
27-May	0	0	0	0						
28-May	356	1393	305	42						
29-May	404	1018	269	58						
30-May	165	2170	627	28						
Totals	**8616**	**8915**	**2085**	**319**	**84**	**58**	**105**	**68**	**106**	**102**

Table 3. Numbers of Atlantic salmon smolts recovered by method and occasion or condition at time of recovery (cut and not cut by turbine) from the tailrace of Morgan Falls Power after experiments conducted in 1997.

Method and occasion or condition	Tag colour		Ventral fin clip		Origin	
	Green	Blue	Right	Left	Wild	Hatchery
Electrofished						
1st set of passes	24	1	1	1	1	4
2nd set of passes	6	1	2	0	2	4
Tailrace nets						
Cut	23	1	1	1	20	6
Not Cut	25	0	0	0	5	0

Table 4. Conditions of marked smolts released at the trashracks of Morgan Falls Power during the louver efficiency tests conducted in May 1997.

Date : May 21, 1997.
Location: Trashrack #2 (middle)

Test #1

Test conditions	Time or condition
Time placed in shore box	14:30
Temp. of water in shore box	12.6C
Smolt condition in shore box	good
Smolt placement in release box in forebay	16:30
Temp. of river water at time of release	12.2C
Turbine power production at the time of release	465 kW
Time of smolt release	16:35
Smolt condition at time of release	good

Test #2

Test conditions	Time or condition
Time placed in shore box	14:30
Temp. of water in shore box	12.6C
Smolt condition in shore box	very good
Smolt placement in release box in forebay	16:48
Temp. of river water at time of release	12.2C
Turbine power production at the time of release	465 kW
Time of smolt release	16:58
Smolt condition at time of release	good

Date : May 22, 1997.
Location: Trashrack #3 (river side)

Test #3

Test conditions	Time or condition
Time placed in shore box	14:05
Temp. of water in shore box	13.0C
Smolt condition in shore box	very good
Smolt placement in release box in forebay	16:14
Temp. of river water at time of release	12.5C
Turbine power production at the time of release	465 kW
Time of smolt release	16:22
Smolt condition at time of release	very good

Test #4

Test conditions	Time or condition
Time placed in shore box	14:10
Temp. of water in shore box	13.8C
Smolt condition in shore box	very good
Smolt placement in release box in forebay	16:39
Temp. of river water at time of release	12.5C
Turbine power production at the time of release	465 kW
Time of smolt release	16:45
Smolt condition at time of release	very good

Date : May 22, 1997.
Location: Trashrack #1 (shore side along wall)

Test #5

Test conditions	Time or condition
Time placed in shore box	14:00
Temp. of water in shore box	14.0C
Smolt condition in shore box	V.Good
Smolt placement in release box in forebay	14:19
Temp. of river water at time of release	12.5C
Turbine power production at the time of release	460kW
Time of smolt release	14:21
Smolt condition at time of release	very good

Test #6

Test conditions	Time or condition
Time placed in shore box	14:05
Temp. of water in shore box	13.0C
Smolt condition in shore box	V.Good
Smolt placement in release box in forebay	14:47
Temp. of river water at time of release	12.5C
Turbine power production at the time of release	460kW
Time of smolt release	14:55
Smolt condition at time of release	very good

Table 5. Number of ventral fin-clipped Atlantic salmon smolts recovered by mark, location and occasion of the recovery at the Morgan Falls Power hydro facility during the effects monitoring program conducted in 1997.

		Number recovered	
Location and occasion	Date	Rt. ventral	Lt. ventral
Bypass after release #1	21-May	25	29
Tailrace after release #1	21-May	9	4
Bypass before release #2	22-May	59	29
E. Seine tailrace after release #2	22-May	2	0
Bypass after release#2	22-May	28	55
Bypass before release #3	23-May	40	50
Bypass after release #3	23-May	77	77
Tailrace after release #3	23-May	9	1
E. Seine tailrace after release #3	23-May	4	0
Bypass after all tests have been conducted	24-May	24	22
Bypass after all tests have been conducted	25-May	3	1
E. Seine after all tests have been conducted	26-May	3	0
Bypass after all tests have been conducted	26-May	2	0
Tailrace after all tests have been conducted	26-May	1	1
Mortality before time of release	26-May	1	0
Totals		287	269

Table 6. Numbers of Atlantic salmon marked (left and right ventral fin clips) smolts recovered in the bypass assessment area and in the bypass tank for three release locations along the forebay channel trash racks at Morgan Falls Power station 1997.

	Experiment trial			Post-experiment		
Release location	Rt.vent.	Lt. vent	Combined	Rt.vent.	Lt. vent	Combined
Middle	84	58	142			
Louver	68	105	173			
Wall	106	102	208			
Total recoveries	258	265	523	29	23	575

Table 7. Proportions of smolts recovered by fin clip and location of release for smolts recovered in the assessment facility immediately following an experiment and in the drained bypass tank at Morgan Falls Power station 1997 with acceleration across the louvers for each experimental trial.

	Proportions			Post-experiment			Acceleration
Release location	Rt. vent.	Lt. vent.	Combined	Rt. vent.	Lt. vent.	Combined	factor
Middle	0.848	0.580	0.714	n.a	n.a	n.a	1.26
Louver	0.680	1.050	0.365	n.a	n.a	n.a	1.26
Wall	1.060	1.020	1.040	n.a	n.a	n.a	1.61
All locations	0.863	0.883	0.873	0.960	0.960	0.960	

Table 8. Chi-square values and probabilities of no significant departure from equal distribution test hypotheses for treatments, fin clip (mark), release location and acceleration for smolts released at the louvers at Morgan Falls Power station 1997.

Treatment	Test	X^2	Prob.
Mark	Two grp.	0.0000	1.0000
Release	3x1	12.5216	0.0019
Acceleration	Two grp	4.6850	0.0304

Table 9. Proportions of smolts using the facility, not deflected by the louvers, not surviving through the turbine, potential return rate and potential catch rate. Values shown are mid-points of the distributions used in the simulation exercise.

	At facility	Non-deflect	Mortality	Return rate	Catch rate
Proportions	0.496	0.127	0.409	0.049	0.300

Table 10. Numbers of wild Atlantic salmon smolts affected by the Morgan Falls Power facility estimated at 1997 wild smolt population estimates, facility use, louver efficiency, turbine mortality rates. Potential adult salmon returns were estimated at two times the observed hatchery smolt to adult survival rate and at angling exploitation rates observed in 1996.

		Number of smolt			Potential	
Method	Wild smolt Pop. est	Entering power canal	Through turbine	Mortalities	Adult returns	Angled
Tagged	16,529	8,198	1,041	426	21	6
Clipped	17,829	8,843	1,123	459	22	7

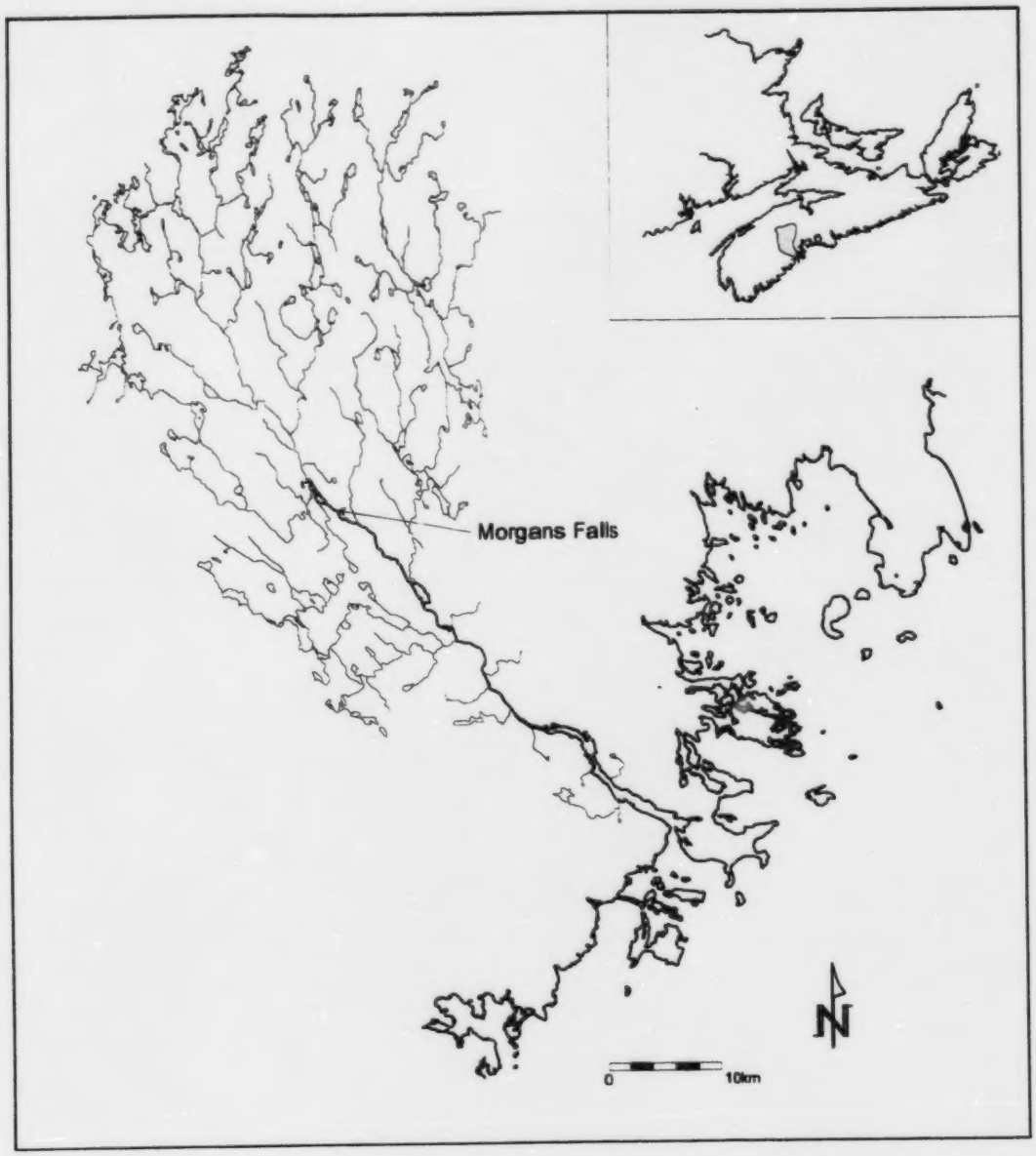


Figure 1. Map of LaHave River, Lunenburg County, Nova Scotia showing location of Morgans Falls.

Figure 2. Site plan of Morgan Falls Hydro and Morgans Falls Fishway, LaHave River, Lunenburg County, Nova Scotia.

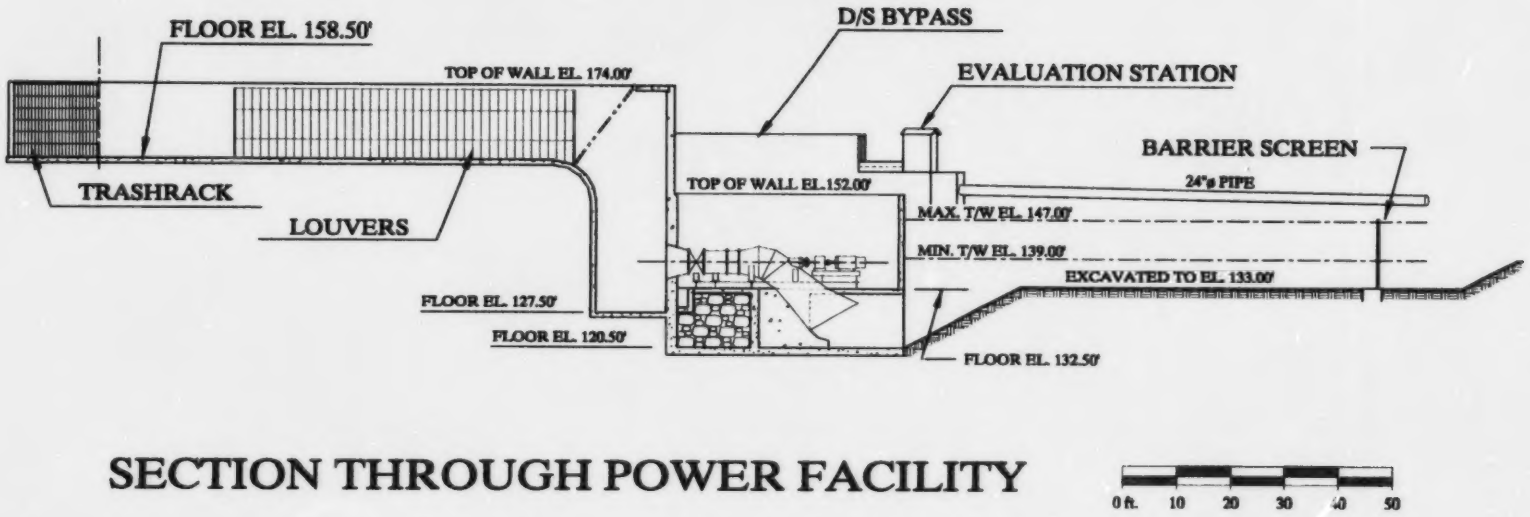
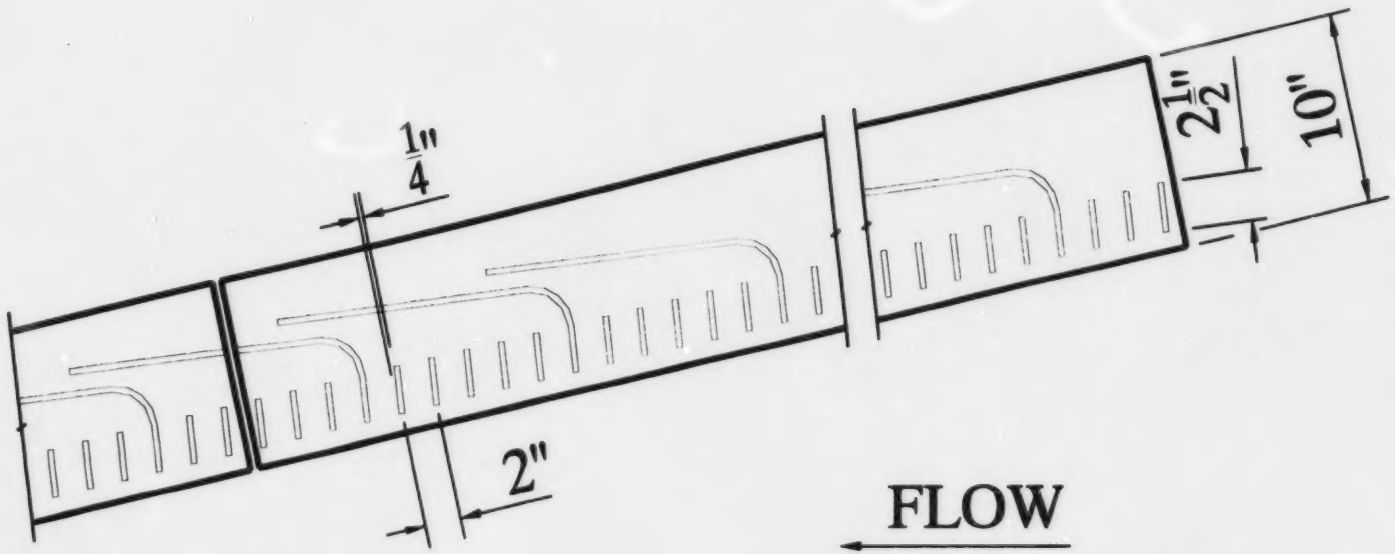


Figure 3. Section through the Morgan Falls Power facility, LaHave River, Nova Scotia.



DETAIL OF LOUVERS

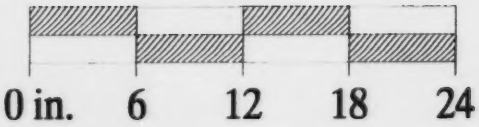
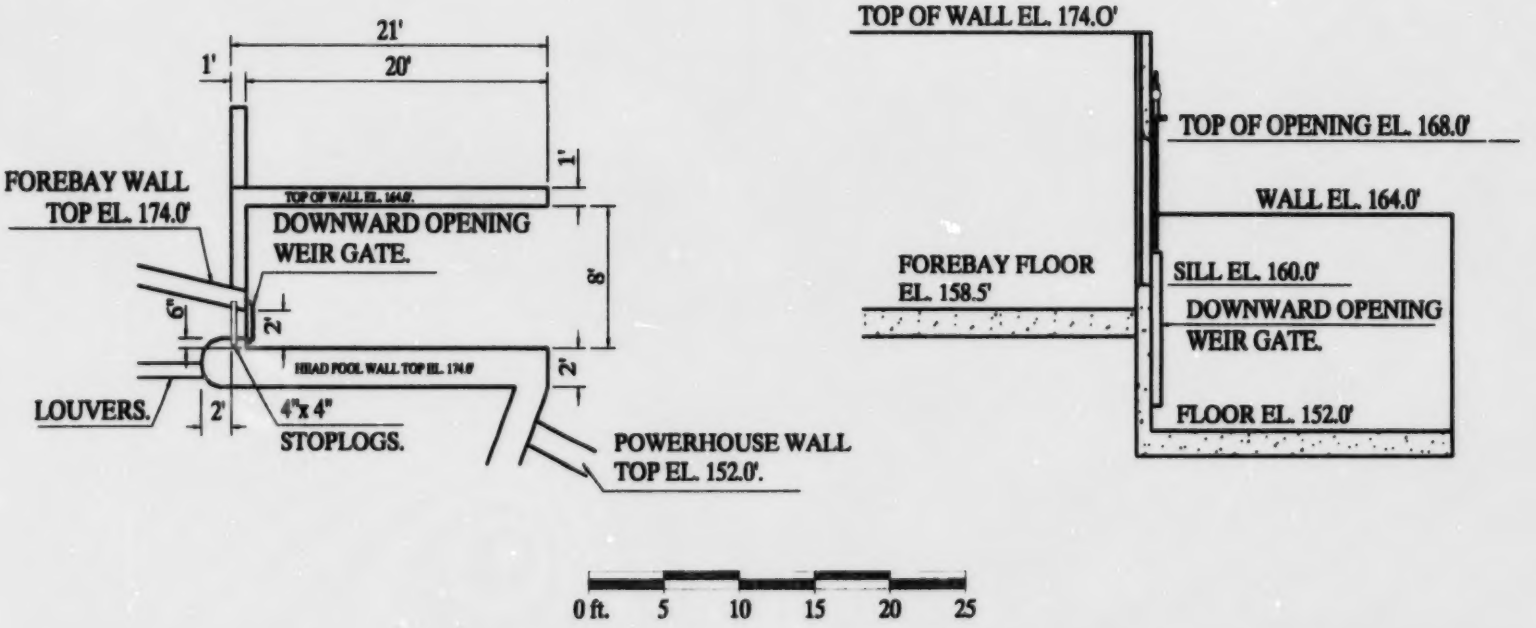


Figure 4. Detail of louver design at Morgan Falls Power facility.



PLAN OF ENTRANCE TO D/S BYPASS

SECTION OF ENTRANCE TO D/S BYPASS

Figure 5. Plan and section of the entrance to the downstream fish by-pass in the Morgan Falls Power forebay.

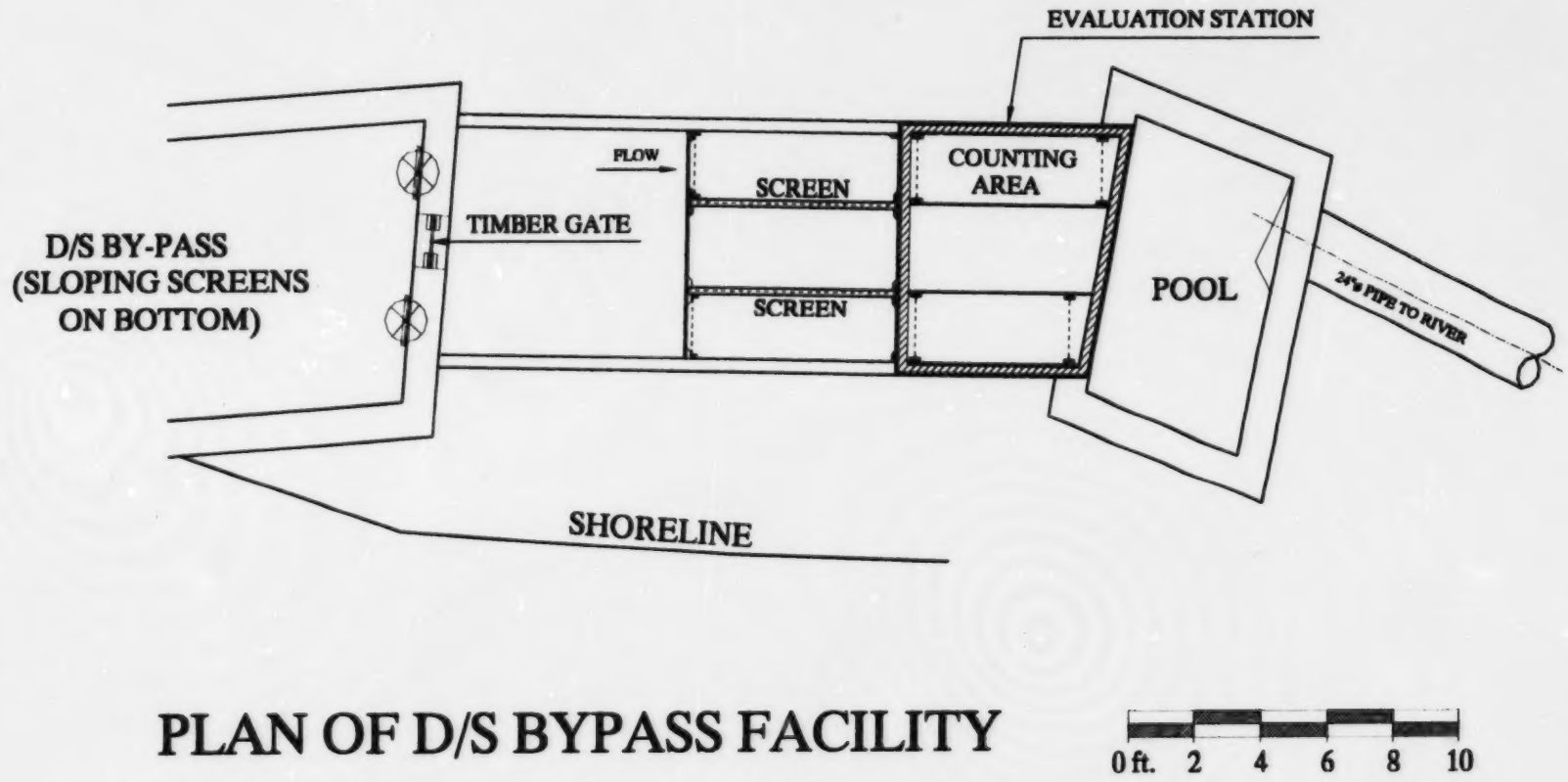


Figure 6. Plan of downstream bypass and assessment evaluation facility at Morgan Falls Power, LaHave River.